INTRODUCTION

Fiber-concrete structures have been widely used abroad for over a hundred years, and there is a positive experience of their effective use in domestic construction. The designs can be made with both fiber and combination reinforcement when there is fiber and rod or wire reinforcement. The range of applications is very wide: monolithic structures - roads, transfer of coverings, industrial floors, leveling floors, bridge decks, ignition channels, explosion-proof structures, dams, fireproof plaster, capacities for water and other liquids, finishing of tunnels, spatial coverings and structures, repair of monolithic structures of floors, roads, etc., prefabricated elements and structures - railway sleepers, pipelines, beams, ladders, wall panels, roofing panels and tiles, floating dock modules, offshore structures, explosion-proof structures, slabs of airfield, road, pavement and channel fasteners, cornices, piles, heating elements, elements of spatial coverings and structures, street accessories.

Recent research and publication analysis

The limited use of steel-fiber concrete in our country can be explained by the very low availability of relevant regulatory documentation and the extremely small number of experimental studies and publications describing them in our country. In the world, there are quite a large number of publications on steel fiber and its properties. In these works, many aspects related to the production and use of steel fiber, including the selection of composition of dispersed reinforced concrete, are raised. In Ukraine and in other post-Soviet countries works of K.V. Talantova [1 - 4] are popular. They state that the choice of materials for fiber concrete and the percentage of its composition should be made depending on practical application. According to [2, 4], the characteristics of steel fiber concrete depend on a number of factors.

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Different types of fiber are used in the production of steel fiber concrete. [3] studies the influence of various types of fiber and the percentage of reinforcement on the basic physico-mechanical characteristics of steel fiber (compression resistance, tensile stress during bending, tensile stress during chipping, as well as the effect on the ultimate tensile strain and compression of concrete) were carried out.

The properties of steel-fiber concrete also largely depend on the percentage of reinforcement selected. In [5], an expression was obtained to determine the minimum percentage of reinforcement. [6] shows the dependence of tensile strength on bending on the coefficient of bulk reinforcement, as well as the characteristic of adhesion of fiber to the cement matrix. These expressions were experimentally tested.

In [7, 8], the deformation and strength characteristics of steel fiber concrete under compression, tensile, and torsion were investigated. Short-term and long-term loading at different ages was studied and the characteristics obtained were compared with those of a concrete matrix. Modeling of fiber concrete structure is also described in [9, 10]. In the work of N.F. Rabinovich [10] there is proposed equations for determining the size of fiber diameter corresponding to the parameters of the structure of the concrete used, as well as the coefficients of volume content of fiber reinforcement at known values of fiber diameter.

Many interesting studies have emerged in recent years, which can be explained by new opportunities in experimental research and computer simulation of fiber concrete and fiber concrete structures. In [11], the strength conditions of steel-fiber concrete cylindrical specimens were obtained, the mechanism of their destruction was described, and computer simulations were performed in the LIRA complex. Experimental studies of the samples were also conducted to compare them with the calculations.

In [12], the issues of improvement of structural and mechanical properties of fine-grained concrete were considered on the basis of the use of a new high-adhesion fiber - composite multi-anchor fiber. For this purpose it is proposed to introduce into the concrete mix at the same time a fiber of two sizes: in the form of long and short fibers in a certain ratio. It is shown that in this case there is an opportunity to significantly improve the performance of the concrete matrix. A number of studies are devoted to the effectiveness of the use of fiber from new materials and fine reinforcement of concrete fiber from different materials [13 - 15].

The work of foreign authors in recent years is more focused on the study of the properties of fibrous concrete in structures [16 - 19].

However, all studies of steel fiber concrete structures are of a separate nature rather than systemic, as is the case in the study of reinforced concrete or metal structures.

**Study purpose and objective**

The purpose of this work was to conduct systematic experimental studies of the strength of steel fiber concrete. The tasks of the work consisted in determining the optimal characteristics of the steel-fiber concrete mixture, followed by the study of the cubic and prismatic strength of the fiber concrete at short and long loads.

**Main part of the study**

Since fiber concrete is a composite material, two approaches are commonly used in the study of its physical and mechanical properties, which are commonly used in the work of composites - phenomenological and structural. In the first case, the material is regarded as a certain isotropic system to which the methods of mechanics of a deformed solid are applicable. In this case, the material characteristics are determined on the basis of laboratory studies and tests using the methods of the theory of experiment planning and mathematical statistics. In the second case, structural analysis is used, which implies the expression of the mechanical characteristics of the material through analogous indices of its components, the coefficient of fiber reinforcement, the type and geometric dimensions of the fiber, etc.

In our country, the most widespread is structural approach to the study of the properties of fiber concrete by analogy with reinforced concrete, which allows you to determine the necessary strength and deformation characteristics based on the properties of the original components. This approach is complex, depends on many factors, but it is also convenient in solving the problems of optimal design of fibrous concrete structures.

The phenomenological approach has become widespread in Europe and America. World experience in designing concrete structures shows that the application of the phenomenological approach in determining the physical and mechanical properties of fiber concrete allows the most efficient use of the material and the design of rational concrete structures.

**The experimental studies included two steps.**

The purpose of the first stage was to determine the optimal characteristics of the steel fiber concrete mix. For this purpose, the cubic strength of steel fiber concrete on samples of 100x100x100 mm was determined. The percentage of dispersed reinforcement varied, which was 0.5%, 1.0% and 1.5%, as well as the size of the fraction of large aggregate (crushed stone) - with the size of the fraction ≤ 10 mm in one series of tests and ≤ 20 mm - in the second. At the same time, the cubic strength of ordinary concrete at the same size of a large aggregate was determined. In total, 8 series of tests were carried out on 9 samples in each, the general characteristics of which are given in Table 1.

In the room where the samples were made and subsequently gained strength, the air temperature met the requirements and was 15 ... 20 ° C.

Before preparing the mixture, the right components were selected and the forms were prepared. For the production of samples used metal detachable molds. Before laying the concrete mixture in the form of their inner surfaces were greased with a thin layer of oil.
First, the required amount of each of the components was proportionally determined, and then the concrete mixture was prepared. For the first two series of experiments, a conventional concrete mixture was prepared and molded. Then they made another the same mixture, and it gradually "portions" was introduced fiber, continuing mixing in the concrete mixer until a uniform distribution of fiber in the mixture.

After the formation of specimens of ordinary concrete and steel fiber, they were left under normal conditions. After 5 days, the samples were removed from the forms, labeled, and stored for 28 days from the time of formation under normal conditions.

After storage, the finished specimens were inspected (they should have the correct geometric shape and parallel faces), measured and prepared for testing.

The processing of the results of the first stage of the tests showed that the optimum characteristics of the steel-concrete mixture is a matrix with a large filler of 10 mm (the cubic strength was much higher than the size of the crushed stone 20 mm, in all series of experiments) at 1.0% fibrous reinforcement, since at a higher percentage of fiber reinforcement increased cubic strength was insignificant. This composition was accepted for the second stage of testing.

In all the experiments used cement grade 400 and washed river sand. The water-cement ratio is 0.449. For disperse reinforcement, bent-end fiber made from high-strength wire with a temporary resistance of 1335 MPa was used. The main characteristics of fiber are given in Table 2.

The fiber used is manufactured by Stalkanat-Silur Production Association (Ukraine) in accordance with European standard EN14889-1: 2006 [20]. It is the most common type of fiber, easy to handle, not prone to the formation of "hedgehogs", holds well in concrete.

The objectives of the experimental studies in the second stage were:

1. determination of cubic ( ) and prism ( ) strength;
2. study the nature of , change along time;
3. elasticity modulus and deformation modulus determination.

To solve these problems, 108 specimens of fiber concrete were tested: 54 - with a short-term load application (27 cubes 100x100x100 mm and 27 prisms 100x100x400 mm) and 54 - with a long load (in the same proportion). A batch of concrete samples similar in quantitative composition was tested at the same time.

Cubes of concrete and fiber concrete were subjected to destruction by compression in a test facility with a loading rate, which provides an increase in the design stress in the sample before its complete destruction. The YBM-50 press was used as the test unit (figure 1). The cubes were set strictly in the center of the plate of the press. They turned on the equipment and gradually loaded the samples before their destruction.

Tests of specimen cubes for compression from the same manufactured batch were performed at the age of 28 days, and then - at the age of 370 days. In this case, the cubic strength of ordinary concrete during the observation increased by 3.5 MPa, which is 11.3%. Fiber concrete strength increased by 10.1 MPa over the same period, ie by 31%. And if, by the time of the set of branded concrete strength (28 days), the strength of fiber concrete was only 4.7% higher than the strength of ordinary concrete, then almost a year later this difference increased to 24%.

It should also be noted the fundamental difference in the nature of the destruction of the test cubes. If the concrete samples are destroyed in the classical scenario, then the cubes of steel fiber concrete even after the loss of bearing capacity do not change their geometric shape. The only noticeable difference "before and after" - the presence of cracks and increase in the transverse dimensions in the direction perpendicular to the plane of action of the load (from 10.0 to 10.4 cm).
It should be noted that all without exception samples that have been under the influence of continuous load for a year have increased their load capacity. The higher the level of load, the more compacted the concrete, and, of course, the higher its durability. Samples loaded to 0.8 (from cubic or prism strength respectively) for 370 days increase their load capacity by 40.5%. At the same time, in the sample loaded to 0.3 the long-term strength increased by 18.3%.

When testing concrete prisms with dimensions of 100 × 100 × 400 mm, twin specimens were combined into groups and series. Samples of each group were made in one step. Prisms (like cubes) were concreted in metal cassette formwork. The concrete mixture was made in a free fall concrete mixer. The formulation was further mixed manually for greater uniformity prior to formworking. Prior to the experimental studies, the samples were stored at a temperature of 18–24°C. Before testing the side faces, the prisms were glued on to mount clock-type indicators.

The method of short-term and long-term testing of samples was made taking into account the recommendations of normative documents for testing concrete.

Determination of the modulus of elasticity and prism strength was preceded by centering the samples from the physical center by applying test loads that cause stresses up to 0.2 of the prism strength. The centering sought to ensure that the deformations along the four faces of the specimen were approximately the same and almost completely reversible. The workload was carried out in steps of 0.1 from prism strength. At each load stage, deformations were measured. The maximum force perceived by the sample prior to fracture was taken as the value of the destructive load.

Continuous loading of the samples was carried out in power stands, consisting of 4 metal rods with a diameter of 46 mm, to which rigid load plates (4 pieces) were attached by means of threaded connections at certain levels. In order to maintain the load during long-term tests at a given level, the transfer of forces from the hydraulic jack to the studied prisms was carried out through a power unit consisting of 4 springs and 2 load plates. The power of each spring is 100 kN.

All forces made by the power unit are balanced within the upper and lower load plates. From the installation to the foundation is transferred only its own weight and a possible dynamic impact during the fragile destruction of the prisms. Prior to loading, each spring cartridge is calibrated using a sample dynamometer (500 kN) mounted at the location of the experimental sample. The load during the experiment was maintained at the required level and controlled by deformation of the spring block and the pressure gauge of the pumping station.

On the height of the installation in one power line, that is, in 2 floors, there were 2 samples: one of ordinary concrete, and the other - of steel fiber. Thus, throughout the experiment (370 days), the mode and load level for both samples were exactly the same.

To determine the bearing capacity, as well as to compare the results of short-term and long-term loading, in each group of samples 3 prisms were brought to destruction by short-term load on the hydraulic press. Five prisms of each concrete composition were loaded with a long load in the power stands and 4 prisms of each group were stored until the end of the experiment to determine the corresponding prism strength. As a result of short-term testing, it was found that the prism strength of ordinary concrete was 235 kN and that of steel fiber concrete was 252 kN.

To cover the entire operational spectrum of the stress state of real reinforced concrete elements, levels of 0.3 were assumed as continuous load levels; 0.4; 0.5; 0.67 and 0.8 from short-term destructive loading. In figure 2 presents the results of long tests for three levels - 0.3; 0.5 and 0.8. The solid lines show the deformation of the concrete, and the dashed lines show the steel concrete. The creep deformation of steel fiber is on average 20% lower than that of concrete.

![Figure 2 Long-time tests results.](image)

**CONCLUSIONS**

The optimal characteristics of the steel fiber concrete mixture is a matrix with a large filler of 10 mm at 1.0% fiber reinforcement, since at a higher percentage of fiber reinforcement the increase in cubic strength was insignificant. Before the destruction of cubic specimens of steel fiber concrete, cracks along the axis of action of the short-term compressive load were observed. The destruction of specimens of steel fiber concrete with 0.5% of disperse reinforcement and ordinary concrete was fragile, while in the case of reinforcement of 1.0% and 1.5% brittle fracture was not observed.

The development of deformations under prolonged loading can be conditionally divided into 3 stages. In the first stage there is an accelerated deformation. The deformations that occurred during this period make up almost 75% of the total deformations during the whole observation period. In the second stage of deformation occurs at a relatively constant rate, ie, the deformation increase is carried out practically according to a linear law. At a load level of 0.3 R stable linear part begins after 35-40 days, for the level of 0.8 - after 65-70 days. The deformations appeared at this stage make up 20-23% of their total size. And finally, in the third stage, the growth rate of deformation is almost approaching zero. The deformation change graph is almost parallel to the horizontal axis.

Prisms made of steel fiber concrete, which have been in operation for 370 days under the influence of prolonged loading, have increased the load-bearing capacity, depending on the load level, by 30-50%. The higher the load level, the higher the durability. When reloading to the destruction of deformation of steel-fiber prisms changed according to linear law. This is explained by the fact that in the process of three-stage loading was elongated transient creep of concrete.
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